HEAT TRANSFER

FOR

VARIOUS ANGULAR POSITIONS ABOUT A PIPE AT RIGHT ANGLES TO ~~A~~ FORCED AIR FLOW

By

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Professor A. L. Merrill
Secretary of the Faculty
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Cambridge, Massachusetts

Dear Sir:

In accordance with the requirements for the Degree of Master of Science, we herewith submit a thesis entitled: "Heat Transfer for Various Angular Positions about a Pipe at Right Angles to a Forced Air Flow".

Respectfully submitted,

ACKNOWLEDGMENT

The authors wish to express their deep appreciation of the invaluable assistance rendered by Professors W. P. Ryan and W. H. McAdams, and Messrs. T. B. Drew and J. J. Hogan in the compilation of this thesis.

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ABSTRACT OF THESIS

Dickermann's[9] work on heat transfer for various angular positions about a pipe at right angles to forced air flow has been continued during this investigation. The rates of heat flow were determined by dividing the condensing surface of the pipe into separate sectors and segregating the condensate from each sector. The pipe used was that of Dickermann but was modified by replacing the bakelite segregating strips with brass strips. The remainder of the apparatus was suitably modified.

The results obtained were of little quantitative significance but were useful in the discovery of difficulties underlying the procedure and pointed the way toward further modifications.

INTRODUCTION

INTRODUCTION

Foreward

An appreciable quantity of data has been collected in past years which is of considerable value in determination of overall* coefficients of heat transfer for forced air flow at right angles to a cylindrical pipe. In addition to these data several theoretical equations have been suggested. Furthermore, attempts have been made to correlate the data of the past by theoretical equations. These have been only moderately successful so that semi-empirical correlations of the experimental data are being used at the present time largely for computing rates of heat flow. Very little work has been done, however, which throws any light upon the mechanism of this heat transfer, the knowledge of which is essential to a theoretical equation.

When a stream of fluid passes around a pipe and at right angles to its axis, hydrodynamical and aerodynamical work has shown isothermal variations of surface velocity and nature of flow. Hence, there is good reason to believe that the rate of heat flow is not constant at all points around the

*Throughout this discussion, the term overall coefficient shall refer to the average heat transfer coefficient of the entire pipe from metal to air.

surface of the pipe. It is possible to measure temperatures and velocities near and at the surface of a cylinder. Experimental difficulties in obtaining precise data of this kind have led to attempting a direct determination of the variation of the rate of heat flow over the surface. The development of such a method, begun by Dickermann[9], is continued in this thesis.

Statement of Main Problem

The problem resolves itself into a determination of the rates of heat flow from various sections of a hot cylinder placed perpendicularly to a stream of air.

Object

It is hoped that a new equation for heat transfer may be obtained which will not only give accurate values of overall transfer coefficients, but will also apply to many special cases which are frequently encountered and which cannot be solved by use of the present equations. In carrying out this problem, attention is also paid to the effect of external conditions upon the rates of heat flow since the theory of the phenomena is at present inadequate to allow the data to be readily corrected. By determining the effects of external conditions upon the values of the heat transfer coefficients, the mechanism should be more clearly understood and a correct relation obtained.

REVIEW OF PREVIOUS WORK

There has been very little work done in the past which might be said to have a direct bearing on the subject. No one has attempted to measure anything except overall values for the coefficient of heat transfer. Nevertheless, there are a few papers that have been published which are of minor interest.

J. T. Morris[1] determined wind velocities at various angles about a rod. This was accomplished by means of a Wheatstone bridge device, the fundamental underlying principle being the fact that the resistance of special types of wire vary considerably with change of temperature. Morris has constructed numerous diagrams showing the velocity distribution at various angles, at various distances from the rod, and for different air velocities.

Boussinesq[2] whose work was reviewed by Russell[3], developed several mathematical equations for the convection of heat from a body cooled by a stream of fluid. His work is of special interest because elliptical pipes are treated in detail. This has, of course, no immediate bearing upon the subject now being considered.

L. V. King[4] derived mathematical equations for the rate of heat flow by convection. King's measurements were made by measuring the resistance of platinum wires of extremely small diameter.

T. E. Stanton[5] relates the experimental work of Jakeman. This work was carried out with a hot pipe and the velocity and eddy effects were determined electrically.

Rubach[6] mapped out the field when a fluid flows past a pipe. Photographs were made showing the stream lines. The data of Rubach checks fairly well the data of Morris. The stream lines are uniformly separated when they approach the pipe but must split into two sections as they go around it. When reunion takes place eddies are formed at the back of the pipe. This accounts for the fact that the fluid velocity past the pipe is high near the front, then decreases and finally at the rear, it increases due to the eddies.

The work of Hughes[7] resembles that of the present investigation. A similar apparatus was used and steam was passed through the pipe. However, the pipe was not divided into sections and only an overall coefficient of heat transfer was determined. With a very few modifications, the set-up of Hughes might have been used to carry on the present work.

Chappell and McAdams[8] have developed the well known Chappell equation which gives reasonably accurate data for the estimation of overall heat transfer coefficients.

Dickermann[9] started the work which is now being conducted. However, the data of Dickermann is of little significance. It was shown that his results were abnormally low due to the fact that a leak had developed in the bakelite finned section. This leak was caused by the repeated expansion and contraction of the bakelite. Since bakelite and brass have different coefficients of expansion, it is easy to understand why the bakelite had pulled away from the brass. Even though these data are of little quantitative significance, they demonstrate, in a qualitative way, just how the rate of heat transfer varies about the pipe. In brief, Dickermann's results may be considered as relative and not as absolute values of the heat transfer coefficients.

REPORT

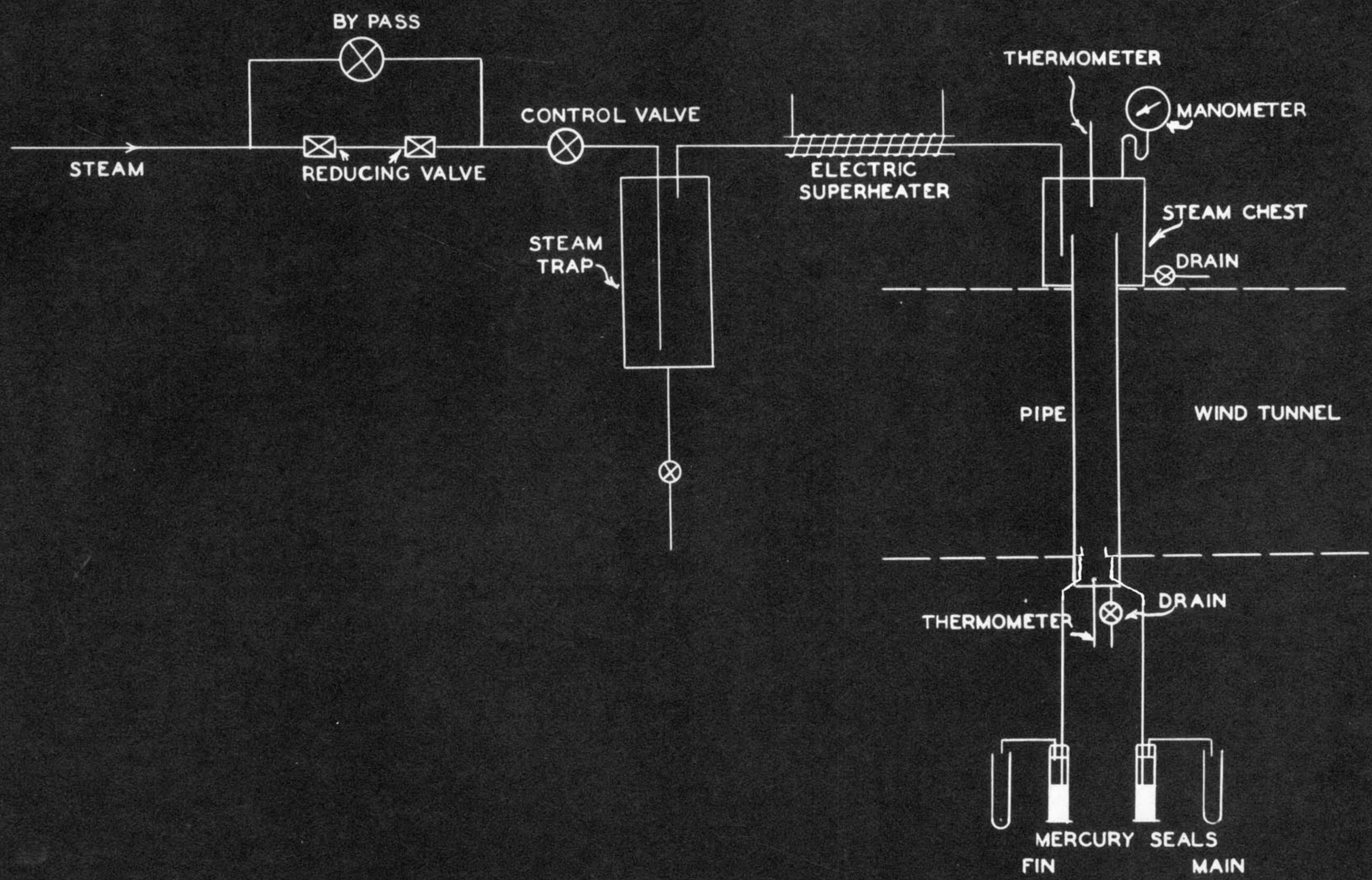
DESCRIPTION OF APPARATUS

General Set-Up

Steam, which has been made as free from air as possible, is passed through a proper set of reducing valves and a superheater so that its pressure is slightly above atmospheric and so that it carries a few degrees of superheat. This steam is passed into the specially constructed pipe where condensation occurs and the fin and main condensates are then removed. This removal is effected through mercury seals so that the pressure throughout the pipe is maintained at a value slightly above atmospheric. The special pipe is placed in a wind tunnel through which air is being drawn by means of a large electrically driven fan. The pipe is so placed that the air flows at right angles to it.

Wind Tunnel

The wind tunnel used was that employed by Dickermann[9]. This tunnel was constructed of 3/8 inch wood veneer and was of rectangular cross section, 2 feet wide and 3 feet high. The straight



PIPING DIAGRAM

section was 8 feet in length, and was connected to the fan by a housing, 5 feet 4 inches long, having the shape of an octagonal frustum of a pyramid. At the fan end, the cross section was circular, the diameter of the circle being 56 inches.

At the entrance of the wind tunnel was placed a crate or grid which straightened out the stream of air. This crate was constructed of galvanized iron strips 2 inches wide and placed together to form a network of 2 inch squares.

In the front of the tunnel, was placed a pitot tube which was connected to an Ellison draft gauge. This draft gauge was filled with kerosene of specific gravity nearly equal to that of Ellison oil. The pitot tube was located in the center of the tunnel, (23) inches beyond the front. The special pipe was located in the center of the tunnel and 36 inches downstream from the front.

Fan

The fan employed was a Sturtevant number 9 design 5. Its rated capacity was 16,900 C.F.M. at 460 R.P.M. This fan was driven by a belt which was connected to an electric motor.

Motor

The motor used was a 3 HP direct current, shunt connected motor, equipped with a shunt field resistance so that the speed was easily controlled. A tachometer was used to obtain the speed of the fan, and after the first twenty-five runs a speedometer run on the belt. This speedometer was merely used to indicate any fluctuations in speed which might occur between the time of tachometer readings.

Steam System

During the first part of the investigation, the steam used was obtained directly from the Institute steam line. This steam was at high pressure and was reduced by means of two reducing valves to a pressure of approximately 10 inches of water. Due to the fact that this steam contained air, it was found advisable to generate steam from deaereated water. This was accomplished by the use of a 40 gallon household boiler and gas heater.

A by-pass around the reducing valves was used in order to facilitate the heating of the apparatus at the start of the run. A steam trap was located in the line just beyond the second reducing valve. After passing through the trap, the steam was superheated by heating the bare pipe with Bunsen burners. A new superheater has been constructed for future work. This heater consists of fifty feet of nichrome wire, the resistance of which is about 10 ohms., wrapped about a pipe which has been previously coated with alundum cement. A rheostat placed in series with this resistance wire permits proper adjustment.

The superheated steam then flowed into the special pipe. Its temperature was measured by means of a calibrated thermometer while its pressure was measured with an open water manometer. A small portion of the non-condensed steam was blown out through the bottom of the special pipe and its temperature was also taken to insure the absence of any moisture in it. The purpose of this blow-off was to free the pipe of any air which might collect or accumulate during the run.

The pressure was maintained at a constant value by means of a needle valve in the line. In order to maintain this pressure it was essential that the condensate from the various sections of the pipe be led off through mercury seals. These consisted of hydrometer jars partially filled with mercury beneath the surface of which a condensate tube dipped. By adjusting the mercury level, the condensate could be led out at various pressures.

Special Pipe

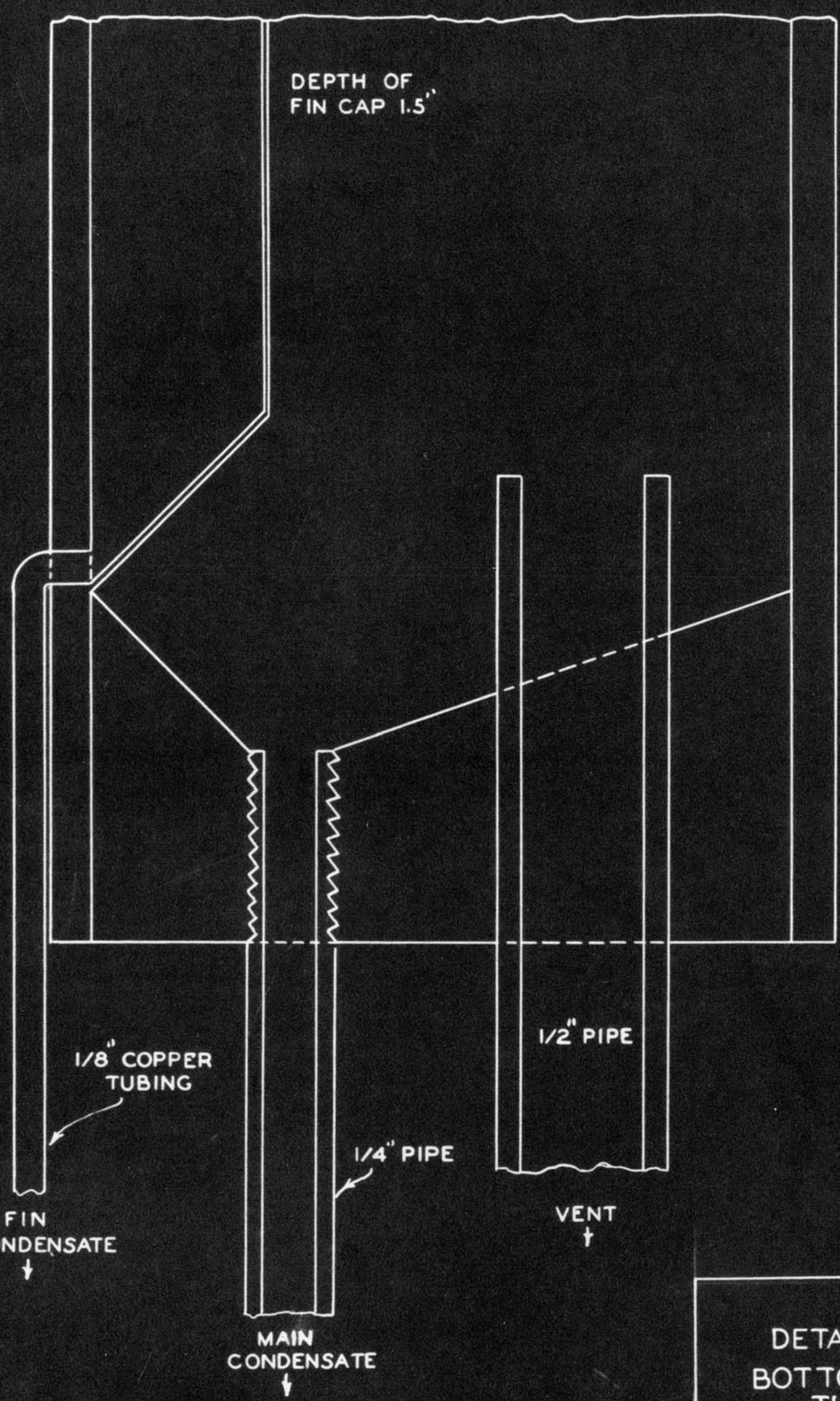
For this work two pipes of slightly different design have been employed while a third was constructed during the final month of the investigation. Dickermann[9], in an endeavor to exclude any effects resulting from the presence of increased surface area, placed bakelite fins inside the brass pipe. These bakelite fins had to be fastened with small set screws and litharge. Consequently, the fin cup soon developed a leak. It is thought that the difficulty was due to the difference in the coefficients of expansion of bakelite, litharge, and brass. The description of Dickermann's pipe are given in detail in his thesis and will not be considered here.

The data of this investigation was obtained from the Dickermann pipe after it was modified. This modified pipe will hereafter be referred to as special pipe number 1. The bakelite fins were removed and thin brass fins substituted. These fins were soldered into the slots which were originally milled for the 1/8 in. bakelite. Since the brass strips were 1/16 in. thick the slots had to be built up with small pieces of brass. Then the strips were inserted and soldered into place. They extended out into the pipe a distance of 3/4 in. The bottom of the pipe was modified as shown in the accompanying sketch and photograph. This modification consisted of a vent through which a small amount of steam might be blown off.

The sketches and photographs of special pipe number 2 are herein included. This pipe has nine sections separated by fins placed twenty degrees apart. These fins extend 1/8 in. towards the center of the pipe and are made of brass 1/32 in. in thickness. The brass pipe has an inside diameter of 3 in. and a wall thickness of 1/8 in. The brass tube extends 4 in. below the tunnel. These four inches serve as a steam jacket for the condensate ducts, since it is found necessary to prevent condensation in them. At the top of the tube a 6 in. brass pipe 1 ft. in length is attached by means of two brass castings. This pipe serves both as a steam trap and header and also the thermometer and manometer are connected into the top of it.

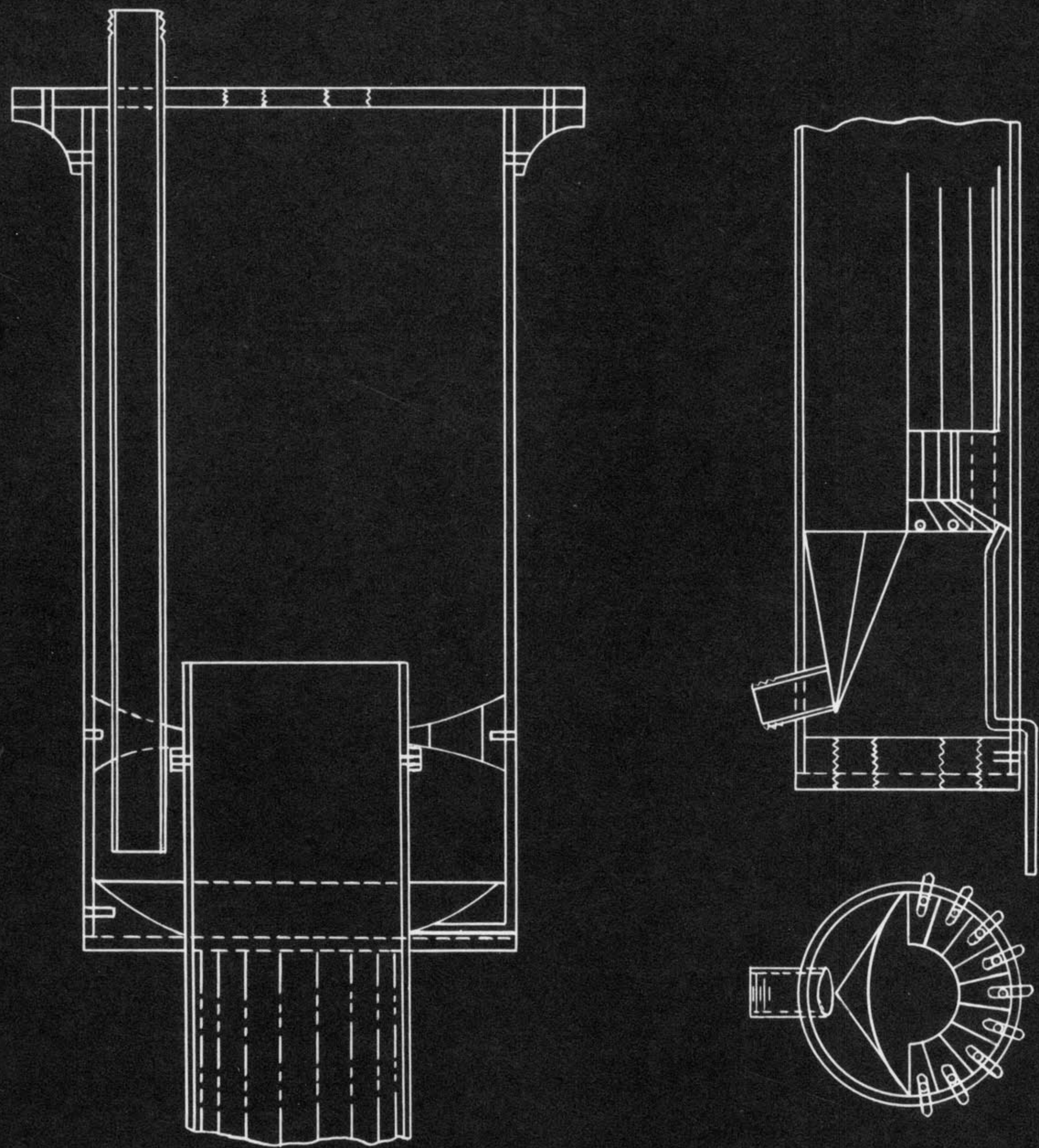
Thermocouples

Two copper-ideal thermocouples were soldered into slots placed upon the outside surface of the special pipe in the region between the fins. The cold junction was immersed in a quart Dewar flask filled with melting ice. The wires chosen for these couples were very small so that conduction of heat from the pipe through them was negligible. A millivoltmeter was used to measure the electromotive force. It should be noted that too much stress should not be placed upon the thermocouple readings as an indication of the surface temperature. It was difficult to attach the couples so that a definite surface temperature could be measured and, in addition, the hot junctions were loosened by the continual waving of the wires in the wind.



DETAIL OF
BOTTOM OF
TUBE

APPOXIMATE SCALE: 2" = 1"



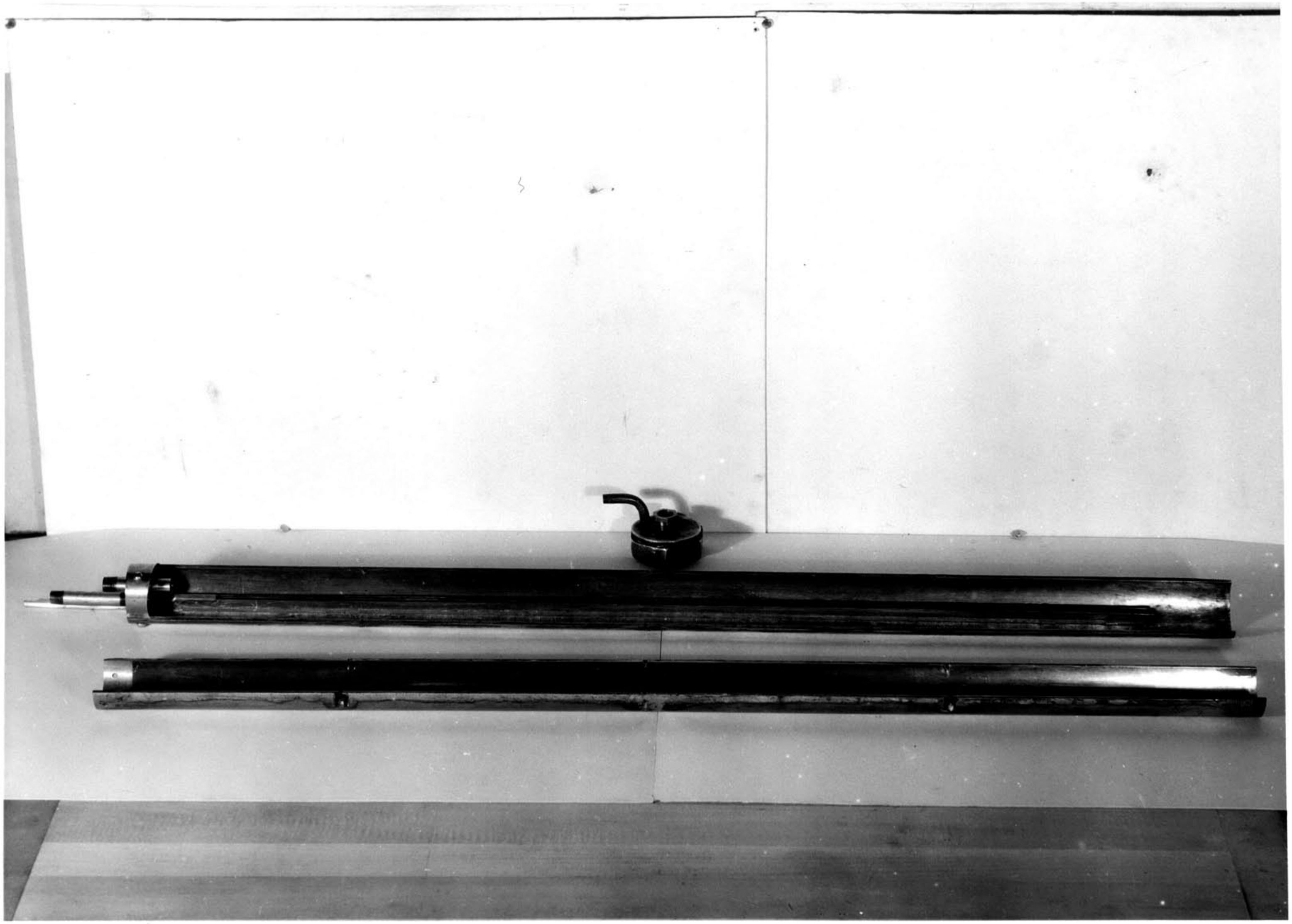
BRASS PIPE

#2

SCALE 1/8" = 1"

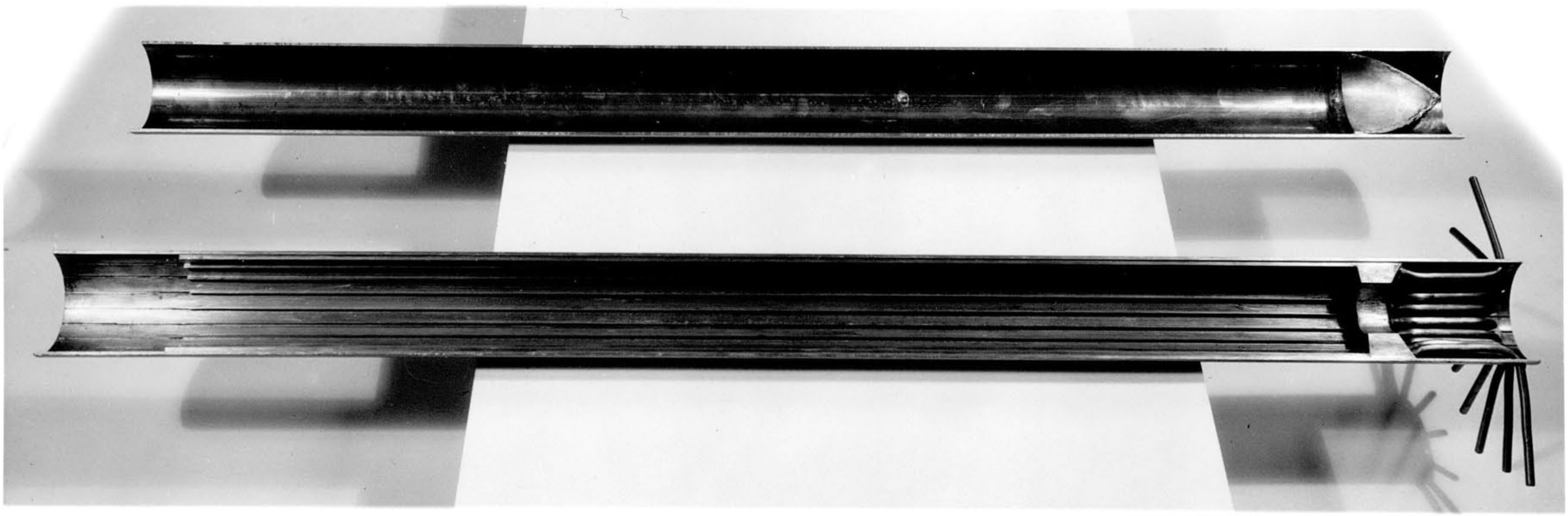
PHOTOGRAPHS OF SPECIAL PIPE

NUMBER 1



PHOTOGRAPH OF SPECIAL PIPE

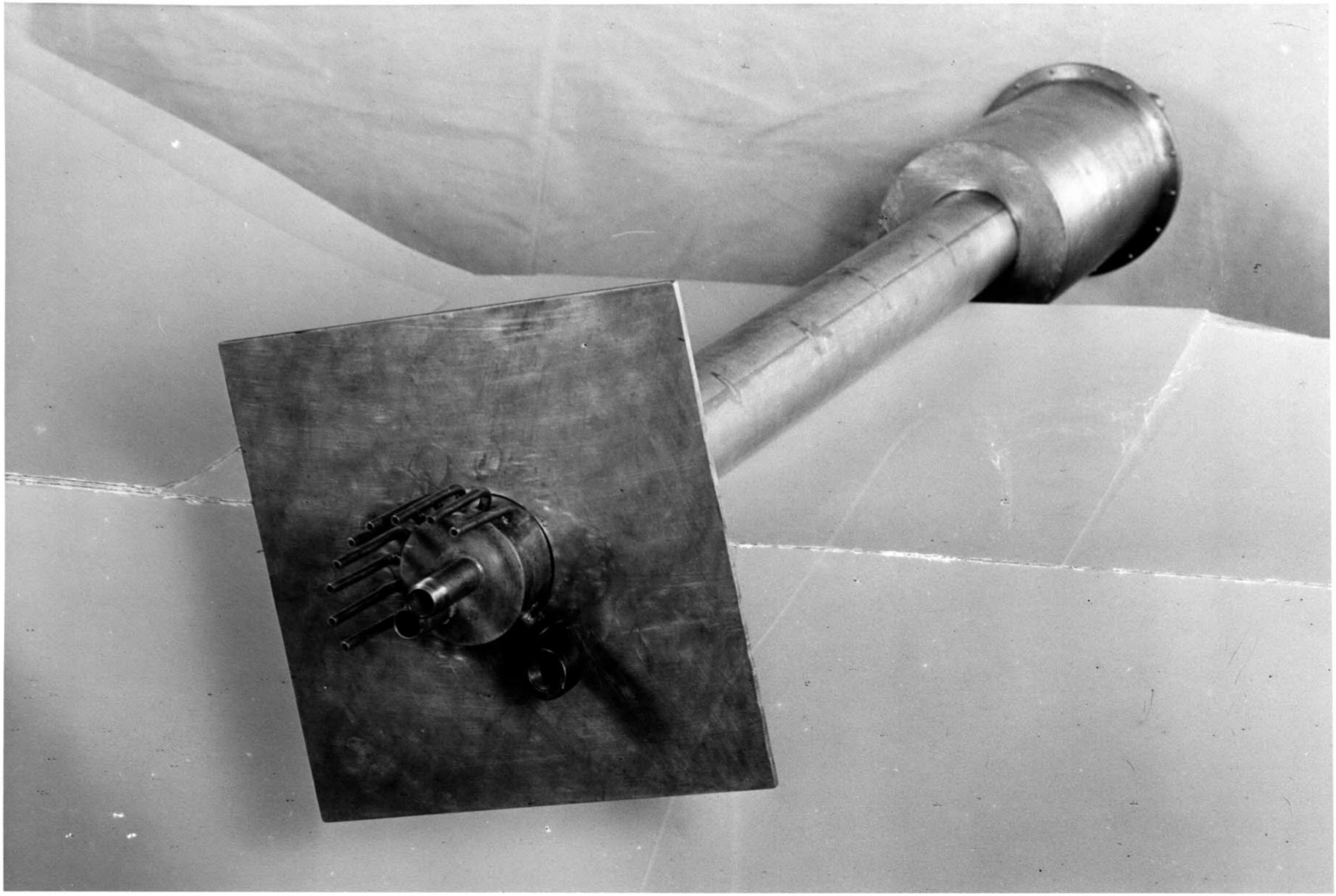
NUMBER 2



PHOTOGRAPH OF SPECIAL PIPE

NUMBER 2

ASSEMBLED.



GENERAL EXPERIMENTAL PROCEDURE

A. Procedure for Runs Using Special Pipe No. 1

The draft gauge and millivoltmeter were set at initial readings of zero. Then the fan was started and adjusted to the proper speed by altering the shunt field rheostat. The residual water was drained from the steam line and apparatus and the steam turned on. All of the valves were open (including the by-pass) and the apparatus allowed to heat up for several minutes. The steam was allowed to blow out through the three outlets at the bottom of the special pipe thus freeing it from air. The gas superheater was adjusted to give a superheat of a few degrees.

When the apparatus had reached a constant temperature, the mercury seals (having been previously adjusted and filled with water) were connected. The by-pass was slowly shut off and simultaneously the valve in the vent line and on the steam trap were gradually closed until only a small amount of steam was allowed to bleed through. The pressure was then adjusted to approximately eight inches of water by means of the needle valve. The run was started when the rate of flow of the condensate was uniform.

Every fifteen minutes for a period of two hours and a quarter readings were taken. These readings included temperatures of entering steam, outlet steam, and air, thermocouple readings, fan speed, draft gauge, and pressure readings. At the conclusion of the run, the pressure was adjusted to its initial value, the condensate removed and weighed. Finally, the millivoltmeter and draft gauge were checked for their zero reading.

B. Modified Procedure for Special Pipe No. 1

After several runs were made as described above, it was found desirable to modify the procedure as follows:

Instead of using the Institute steam line, the boiler and heater were employed to generate the steam. In order to free the boiler steam from non-condensable gases, the complete apparatus was filled with water, the valve between the boiler and apparatus was closed, and the water in the boiler was boiled continuously for several hours. Then the valve was slowly opened and the water in the apparatus was blown out and replaced by the air-free steam. From this point onward, the procedure was the same as the one described above except for the manner in which readings were taken. Readings were now made at five minute intervals and the condensates weighed every fifteen minutes. Therefore, the change in ratio of fin condensate to total could be observed at regular intervals during the run.

In procedure A and B, the ratios of fin condensate to total could be obtained for the various angles about the pipe by turning the pipe as a whole with reference to the wind tunnel. This was accomplished by loosening the union at the point of entrance of the steam into the special pipe.

C. Procedure for Special Pipe No. 2

The procedure is to be identical with the modified procedure explained above. However, thermocouples are not to be employed as too many would be required and the accuracy obtained is insufficient to warrant their installation. The condensate is to be withdrawn from the nine finned sections and from the main section simultaneously. Thus nine values of the coefficient of heat transfer will be obtained from every run and it will be unnecessary to turn the pipe.

TREATMENT OF RESULTS

The experimental results are treated in the following manner:

1. The data is averaged for each of the runs.

2. The average value of ΔT from steam to air is obtained. This value has been taken to be equal to $212° - t_{ave}$.

Note: The value of 212° is slightly low due to the fact that the pressure is slightly above atmospheric.

3. The total surface area and the surface area of the finned section may be calculated from the dimensions.

4. From the amounts of condensate, the values of Q/Θ can be obtained for the finned section and for the total.

5. From these values, the coefficient of heat transfer can be calculated for both the finned section and for the whole pipe.

6. By measuring the surface temperature on the outside surface of the pipe, these coefficients from metal to air can also be calculated. Hence the

need for average thermocouple readings. These values may be checked by calculating the values of the coefficients from steam to metal by use of already established equations and combining these values with the overall values from steam to air. This procedure will have to be employed when the new pipe is installed as no thermocouples will be placed upon its surface.

7. The values of the overall coefficients of heat transfer can be checked by comparison with the values of Chappell and McAdams[8].

8. By associating the values of the heat transfer coefficients with the average air velocity, air temperature, air humidity, and steam pressure, a general conclusion may be reached and a general equation for heat transfer may be promulgated.

DISCUSSION OF RESULTS

General Discussion

The actual results which have been obtained are of no great quantitative significance and therefore no calculations of the coefficients have been made. However, the data which has been obtained is of considerable value when interpreted in the proper manner.

First of all, the data verifies the results of Dickermann[9], but lean towards greater accuracy. Dickermann's values for the coefficients of the finned section are very much too low due to the leak in the fin cup. Because of this leak, an appreciable amount of fin condensate was discharged through the main condensate outlet. The average fin condensate (as the fin is revolved) should be 1/18 of the average total condensate. Dickermann obtained an average fin condensate which was about eighty percent too low. The brass fins eliminated the leak and consequently the data checked, to a reasonable degree, the predicted average ratio of 1 to 18.

The results were not accurate enough to be useful in the derivation of a rigorous heat transfer equation. The inaccuracy of the results was finally attributed to the presence of non-condensable gases in the steam. This hypothesis was checked by injecting nitrogen into the steam during one of the runs. The rate of condensation from the finned section fell rapidly, while that from the main section did not. It was concluded that the vent succeeded only in freeing the main portion from gases but left a film of air in the finned section. In order to eliminate this difficulty, the fins in the new pipe protrude only 1/8 inch and are not capped at the top. With the use of nine fins, it is thought that the same conditions will be reached for each of the sections and the results will be on a common basis. This work will be carried on shortly with the new pipe.

The ratio of fin condensate to total condensate (which is a function of the ratio of the coefficients) is highest near the front and lowest 120° from the upstream side. The values at the front and back are intermediate. This can be correlated with the data of Rubach[6] and Morris[1] which predict maximum velocities within the 45° region and minimum at 120°.

ANALYSIS OF DATA

At regular intervals during the process of collecting data this data was analyzed. First, it was thought advisable to make one run for every sixty degrees. With this procedure in mind, runs (Nos. 1-6) were made at 0°, 60°, 120°, and 180°. Then an attempt was made to duplicate one of the runs. This attempt was unsuccessful.

It appeared at this time that the reason for the non-duplication of the results was the fact that the air temperature could not be exactly duplicated. It was thought that the rate of condensation in the finned sector was a function of air temperature, and also of the position of the sector with reference to the flow of air. However, no checks were able to be made at any angular position (Runs 6-20) not even when the air temperatures were almost identical.

After one of the runs had been completed, the fin was blown out and the rate of condensation in the finned sector immediately increased. This led to the theory that air collected in the fin and was not blown out through the vent. This theory was verified by injecting nitrogen into the system during a run (Run 21). The rate was practically unaffected in the main sector but fell rapidly in the small finned sector. The air was attributed to the fact that Institute steam was used. Therefore, to eliminate this difficulty, a boiler and heater arrangement was set up and deaereated steam was used. However, the results (Runs A,B, and C) still were unable to be duplicated. The present theory is that an equilibrium condition is reached inside the pipe very slowly. This theory was strengthened by the results of the detailed run No. C. This run lasted several hours and it was apparent that changes in the external conditions seemed to affect the results only after a lapse of several hours. It is this unsteady state which produces the deviations between supposedly identical runs. By using the new pipe the same equilibrium may be reached simultaneously for all the sectors.

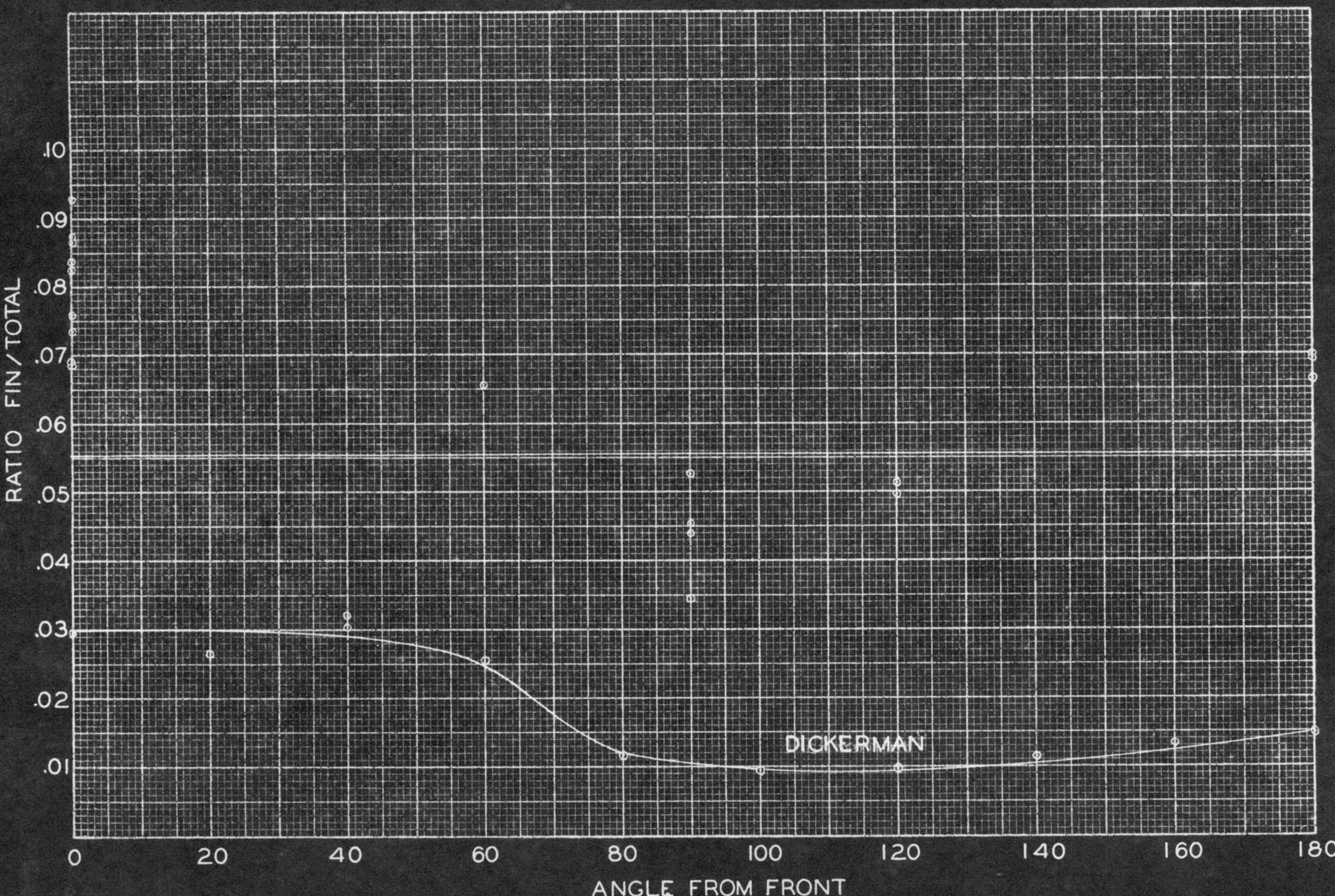
WEIGHTED AVERAGES OF EXPERIMENTAL DATA

Run Number	Angle from Front in Deg.	Barometer mm.	Air Temp. °F.	Entering Steam Temp. °F.	Exit Steam Temp. °F.	Top Thermo-couple mv.	Bottom Thermo-couple mv.	Steam Pressure in. water	Draft Gauge in. wat.	RPM Fan	Time hrs.	Fin Cond. gms.	Main Cond. gms.	Total Cond. gms.	Ratio Fin/Total	Overall H[1] Eng. Unit
1	0	772.2	78.0	256	215	3.6	3.6	8.1	.050	240	2.017	118	1491	1609	.0735	7.8
2	0	775.3	80.4	214	215	3.7	3.5	8.8	.160	450	2.3	199.5	2695	2895	.0689	12.3
3	60	769.3	83.8	214	215	3.5	3.2	8.9	.160	450	2.3	182.4	2596	2778	.0657	12.1
5	120	770.4	76.4	214	215	4.0[2]	[3] 4.0	9.8	.160	451	2.3	152.4	2919	3071	.0497	12.7
6	120	767.5	80.4	214	215	4.0	4.0	9.6	.160	450	2.3	151.3	2810	2961	.0512	12.6
7	180	762.6	81.0	214	214	4.0	4.0	9.6	.165	450	2.3	195.9	2610	2806	.0697	12.0
8	180	760.9	82.9	216	214	3.9	3.9	9.3	.160	450	2.3	180.9	2555	2736	.0662	11.8
9	180	771.0	72.9	214	215	4.0	3.9	9.4	.155	450	2.3	210.5	2820	3031	.0694	12.2
10	90	776.5	85.8	217	215		4.0	9.2	.160	450	2.3	125.8	2640	2766	.0455	12.3
11	90	764.3	74.3	218	215		4.0	9.1	.165	450	2.3	159.4	2860	3019	.0528	12.3
12	90	761.6	81.8	218	215		4.0	9.2	.165	452	2.3	124	2700	2824	.0440	12.1
13	90	776.3	74.4	217	216		4.0	9.2	.165	448	2.3	103.5	2890	2994	.0346	12.1
14	0	758.0	71.5	219	216	3.9	3.9	9.2	.180	450	2.3	252	2810	3062	.0823	12.2
15	0	758.0	76.8	217	215	3.9	3.9	10.3	.170	453	2.3	234.5	2740	2975	.0790	12.3
16	0	750.0	75.6	218	215	3.9		10.1	.180	452	2.3	262	2760	3022	.0866	12.4
17	0	757.3	71.2	221	216	4.1		9.5	.180	453	2.3	240	2920	3160	.0760	12.5
18	0	757.3	70.7	217	215	4.0		10.3	.170	455	2.3	262	2864	3126	.0839	12.6
19	0	761.4	70.3	218	215	4.1		10.9	.180	451	2.3	294.4	2881	3175	.0929	12.5
20	0	761.4	70.6	218	215	4.0		11.2	.165	450	2.3	274	2856	3130	.0874	12.4

[1] See sample calculation in Appendix. [2] New thermocouples were attached after Run 3. [3] Corresponding Temperatures are 206 °F. for 3.9, 210°F. for 4.0, and 212+°F. for 4.1 millivolts.

Notes--(a) See Run 21 in Appendix for effect of injecting air.

(b) Runs A, B, and C are best studied from the data in the Appendix.


RATIO FIN / TOTAL
.10
.09
.08
.07
.06
.05
.04
.03
.02
.01
0
20
40
60
80
100
120
140
160
180
ANGLE FROM FRONT
DICKERMAN

CONCLUSIONS

In the discussion of the results it has been shown:

1. That the data is not sufficiently accurate for the calculation of heat transfer coefficients.

2. That the data checks that of Dickermann fairly well and discloses the difficulties involved in the use of bakelite fins.

3. That the data of Morris, and Rubach is in agreement with the results obtained.

4. That the presence of small amounts of non-condensable gases in the steam renders the results inaccurate.

5. That the use of a new pipe having many shallow finned sections will eliminate most of the difficulties.

SUGGESTIONS AND RECOMMENDATIONS

1. It might be advisable to obtain a wet bulb thermometer reading as the changes in air humidity might have some effect upon the heat transfer.

2. The more simple the steam line is made, the easier it is to maintain constant pressure.

3. The runs should not extend for a period of two hours and a quarter. It appears from the data that one hour runs will give representative results.

4. The tunnel should be extended in length. At present, the air flow is not so straight as it might be. By placing a nozzle on the front of the tunnel accurate air velocities may be obtained. At the present time, the velocities are too low to be measured with a pitot tube with much accuracy.

5. The electric superheater should be employed as this will keep the steam temperature much more constant. Also, the heating will be much more uniform and hot spots on the pipe will not occur.

6. All readings should be made at five minute intervals and condensates weighed every fifteen minutes.

APPENDIX

RUN NO. 1

Barometer - 772.2 mm.

Angle 0°

Time	Thermometer Readings Top	Thermometer Readings Bottom	Thermometer Readings Air	Draft Gauge	R.P.M. Fan	Pressure H_2O	Thermocouple Top	Thermocouple Bottom
2:30	294°	217°	77.5°	.073	240	8"	3.6	3.6
2:44-5	276	216	78	.073	239	8	3.6	3.6
3:00	258	216	78	.073	240	8	3.6	3.6
3:15	252	215	78	.073	240	8.25	3.6	3.6
3:30	252	215	78	.073	240	8.5	3.6	3.6
3:45	246	215	78	.073	241	8	3.6	3.6
4:00	253	215	78	.073	240	8	3.7	3.7
4:15	238	214	78	.073	240	7-7/8	3.7	3.7
4:29	251	215	78	.073	240	7-7/8	3.7	3.7
		Cut at 4:31		↑				
		Zero Reading		.025				

Wt. Fin Condensate = 118 g. ; Wt. main condensate = 1491 g.

Total Condensate = 1609 g.

$$\text{Ratio} = \frac{118}{1609} = .0735$$

RUN NO. 2

Angle 0° Barometer = 775.3 mm.

Time	Thermometer Readings Top	Bottom	Air	Draft Gauge	R.P.M. Fan	Press. H_2O	Thermocouples Top	Bottom
2:24	214°	215°	81°	.161	450	8-1/2"	3.7	3.5
2:39	214	215	81	.161	450	8-1/2	3.7	3.5
2:54+	214	215	80	.160	450	8-1/2	3.7	3.5
3:10	214	215	80	.160	450	8-3/4	3.7	3.5
3:25	214	215	81	.161	450	8-3/4	3.7	3.5
3:40	214	215	80	.162	450	9	3.7	3.5
3:55	214	215	81	.160	454	8-3/4	3.7	3.5
4:10	214	215	80	.160	450	8-3/4	3.7	3.5
4:25	214	215	80	.160	450	9	3.7	3.5
4:40	214	215	80	.160	447	8-1/2	3.7	3.5

Cut at 4:42

Wt. Fin Condensate = 199.5 g.; Wt. Main Condensate = 2695 g.; Total Condensate = 2894;

$$\text{Ratio} = \frac{199.50}{2894} = .069$$

RUN NO. 3

Angle 60° Barometer = 770.6 mm.

Time	Thermometer Readings Top	Bottom	Air	Draft Gauge	R.P.M. Fan	Press. H_2O	Thermocouples Top	Bottom
11:00	214°	215	84	.160	450	8-1/4	3.5	3.3
11:15	214	215	84	.160	450	8-1/2	3.5	3.2
11:30	214	215	84	.160	450	9	3.5	3.2
11:45	214	215	83	.160	450	9	3.5	3.2
12:00	214	215	83	.160	450	9-1/4	3.5	3.2
12:15	214	215	84	.160	450	9-1/4	3.5	3.2
12:30	214	215	84	.160	450	9	3.5	3.2
12:45	214	215	84	.160	450	9	3.5	3.2
1:00	214	215	84	.160	450	9	3.5	3.2
1:15	214	215	84	.160	450	9-1/4	3.4+	3.2

Cut at 1:18

Wt. Fin Condensate = 182.4 g.; Wt. Main Condensate = 2590 g.; Total Condensate = 2772;

$$\text{Ratio} = \frac{182.4}{2772.4} = .066$$

RUN NO. 5

Angle 120° Barometer = 770.4 mm.

Time	Thermometer Readings Top	Bottom	Air	Draft Gauge	R.P.M. Fan	Press. H_2O	Thermocouples Top	Bottom
1:28	214°	215°	74°	.160	451	8-1/2"	3.9	4.0
1:45	214	215	75	.160	451	7-1/2	3.9	4.0
2:00	214	215	76	.166	456	10	3.95	4.0
2:15	214	215	76	.160	450	9	3.98	4.0
2:30	214	215	76	.160	450	8	3.98	4.0
2:45	214	215	76.5	.160	451	9	3.98	4.0
3:00	214	215	77	.165	450	9	3.98	4.0
3:15	214	215	77.5	.162	450	9	3.98	4.0
3:30	214	215	78	.165	450	9	3.98	4.0
3:45	214	215	78	.165	450	9	3.98	4.0
	Cut at 3:46 (Fin Condensate)							
Wt. Fin Condensate = 152.4 g.;								
4:00	214	215	78	.160	450	10	3.98	4.0
4:15	214	215	78	.165	450	10	3.98	4.0
	Cut at 4:19 (Main Condensate)							

Wt. Main Condensate = 2919

RUN NO. 6

Angle 120°

Barometer = 767.5 mm.

Time	Thermometer Readings Top	Thermometer Readings Bottom	Thermometer Readings Air	Draft Gauge	R.P.M. Fan	Press. H_2O	Thermocouples Top	Thermocouples Bottom
10:17	214°	215°	80°	.170	450	9"	3.98	4.00
10:30	214	215	80	.170	451	9"	3.98	4.00
10:45	214	215	80	.170	451	9-1/4	3.98	4.00
11:00	214	215	80.5	.170	451	9-1/4	3.98	4.00
11:15	214	215	80	.171	453	10	3.98	4.00
11:30	214	215	81	.170	449	10	3.98	4.00
11:45	214	215	81	.172	450	10-3/4	3.98	4.00
12:00	214	215	80.5	.170	449	11	3.98	4.00
12:15	214	215	80	.170	450	9	3.98	4.00
12:30	214	215	81	.170	449	8-1/2	3.98	4.00

Cut at 12:35 Zero Reading .01

Wt. Fin. Condensate = 151.3 g.; Wt. Main Condensate = 2810 g.; Total Condensate = 2961.3 g.;

$$\text{Ratio} = \frac{151.3}{2961.3} = .0511$$

RUN NO. 7

Angle 180°

Barometer = 762.6

Time	Thermometer Readings Top	Thermometer Readings Bottom	Thermometer Readings Air	Draft Gauge	R.P.M. Fan	Press. H_2O	Thermocouples Top	Thermocouples Bottom
3:05	214	215	81	.170	451	9-1/4	3.98	3.99
3:20	214	215	82	.170	455	11	3.98	3.99
3:35	214	215	81	.170	449	10	3.98	3.99
3:50	214	214	81	.165	449	9-1/2	3.98	3.99
4:05	214	214	81	.164	450	9	3.98	3.99
4:20	214	214	80.5	.164	449	9	3.98	3.99
4:35	214	214	81	.165	449	8-1/2	3.98	3.99
4:50	214	214	80	.160	449	9-1/4	3.98	3.99
5:05	214	214	80.5	.160	449	10	3.98	3.99
5:20	214	214+	82	.160	449	10	3.98	3.99

Cut at 5:23

Wt. Fin Condensate = 195.9 g; Wt. Main Condensate = 2610 g.; Total Condensate = 2805.9 g.;

$$\text{Ratio} = \frac{195.9}{2805.9} = .0698$$

RUN NO. 8

Angle 180° Barometer = 760.9 mm.

Time	Thermometer Readings Top	Thermometer Readings Bottom	Thermometer Readings Air	Draft Gauge	R.P.M. Fan	Press. H_2O	Thermocouples Top	Thermocouples Bottom
10:12	214°	214°	81°	.160	450	9-1/4"	3.9	3.9
10:30	214	214	82	.161	451	9	3.9	3.9
10:45	214	214	82	.160	451	9	3.9	3.9
11:00	214	214	82	.160	451	8-3/4	3.9	3.85
11:15	213	214	83	.160	455	8-1/2	3.9	3.85
11:30	216	214	84	.160	450	10	3.9	3.85
11:45	214	214	83	.160	449	9-1/4	3.9	3.85
12:00	214	214	84	.160	449	9-1/4	3.9	3.85
12:15	217	215	85	.160	448	9-3/4	3.9	3.85
12:29	216	214	83	.160	449	9-3/4	3.9	3.85

Cut at 12:30

Wt. Main Condensate = 2555 gr.; Wt. Fin Condensate = 180.9 g; Total Condensate = 2735.9 g.;

$$\text{Ratio} = \frac{180.9}{2735.9} = .0662$$

RUN NO. 9

Angle 180° Barometer = 771.0 mm.

Time	Thermometer Readings Top	Thermometer Readings Bottom	Thermometer Readings Air	Draft Gauge	R.P.M. Fan	Press. H_2O	Thermocouples Top	Thermocouples Bottom
1:35	214	215	68	.150	450	9-1/2	3.95	3.85
1:45	215	215	73	.160	450	11	3.95	3.85
2:00	214	215	74	.155	450	9-1/4	3.95	3.85
2:15	214	215	74	.155	451	9-1/2	3.95	3.85
2:30	216	215	74	.155	450	9	3.95	3.85
2:45	214	215	70	.157	449	8-1/2	3.95	3.85
3:00	214	215	74	.160	451	9	3.95	3.85
3:15	214	216	76	.160	452	10	3.95	3.85
3:30	214	216	73	.160	451	9	3.95	3.85
3:45	214	215	73	.160	450	9	3.95	3.85

Cut at 3:53

Wt. Main Condensate = 2820 g.; Wt. Fin Condensate = 210.5 g.; Total Condensate = 3030.5 g.;

$$\text{Ratio} = \frac{210.5}{3030.5} = .0694$$

RUN NO. 10

Angle 90°

Barometer = 776.5 mm.

Time	Thermometer Readings Top	Bottom	Air	Draft Gauge	R.P.M. Fan	Press. H_2O	Thermocouples Top	Bottom
2:32	216°	215°	86°	.160	450	9-1/2		3.95
2:45	220	216	86	.162	450	9-1/2		3.95
3:00	215	215	85	.162	451	9-1/4		3.97
3:15	218	216	86	.160	450	9-1/2		3.97
3:30	220	216	86	.162	451	9-1/4		3.97
3:45	214.5	215	85	.162	451	8		3.97
4:00	219	215	86	.160	451	9-1/2		3.97
4:15	216	215	86	.162	450	9		3.97
4:30	214	215	86	.162	450	8-1/2		3.97
4:45	220	216	86	.162	451	9-3/4		3.97

Cut at 4:50

Wt. Main Condensate = 2640 g; Wt. Fin Condensate = 125.8 g; Total Condensate = 2765.8 g;

$$\text{Ratio} = \frac{125.8}{2765.8} = .0455$$

RUN NO. 11

Angle 90°

Barometer = 764.3 mm.

Time	Top	Bottom	Air	Draft Gauge	R.P.M. Fan	Press. H_2O	Thermocouples Top	Bottom
10:16	216	214.5	76	.166*	450	9		3.95
10:30	217	216	74	.165	450	9		3.96
10:45	215	214	72	.165	450	8-3/4		3.95
11:00	220	215	76	.165	450	9		3.95
11:15	218	215	74.5	.167	450	9		3.95
11:30	224	215	73	.167	450	9-1/4		3.95
11:45	214	214	73	.165	452	9		3.95
12:00	223	215	75	.160	452	10		3.97
12:15	218	214	73	.160	450	9		3.97
12:30	219	214	76	.170	450	9-1/4		3.97

Cut 12:34 *Zero Reading = .005

Wt. Main Condensate = 2860 g; Wt. Fin Condensate = 159.4 g.; Total Condensate = 3019.4 g;

$$\text{Ratio} = \frac{159.4}{3019.4} = .0528$$

RUN NO. 12

Angle 90°

Barometer = 761.6 mm.

	Thermometer Readings Top	Bottom	Air	Draft Gauge	R.P.M. Fan	Press. H_2O	Thermocouples Top	Bottom
5	215°	214°	80°	.170	450	10-1/2"		3.95
5	220	215	82	.160	451	8-1/2		3.95
0	227	215	82	.170	452	9		3.95
5	215	214	82	.165	452	9		3.95
0	219	215	82	.165	451	9		3.95
5	214.5	214	82	.170	452	9		3.95
0	223	215	82	.160	452	9-1/4		3.95
5	215	214	82	.170	454	8-1/2		3.95
0	222.5	215	82.5	.170	452	9		3.95

at 12:43

Main Condensate = 2700 g.; Wt. Fin Condensate = 124 g.; Total Condensate = 2824 g.;

$$\text{Ratio} = \frac{124}{2824} = .044$$

RUN NO. 13

Angle 90°

Barometer = 776.3 mm.

Top	Bottom	Air	Draft Gauge	R.P.M. Fan	Press. H_2O	Thermocouples Top	Bottom
219	216	74	.155	448	9		3.98
214	215	72.5	.155	448	8-1/2		3.98
215	215	74	.162	448	9		3.98
220	216	74	.152	448	9-1/2		3.98
220	216	78	.155	449	10		4.00
214	215	70	.155	449	7		3.98
214	215	76	.150	448	9-1/2		3.98
220	216	77	.150	448	10		3.98
218	215	77		449	10-1/4		3.98
214	216	71.5	.160	449	9		3.98

at 3:48 Zero Reading -.009

Main Condensate = 2890 g.; Wt. Fin Condensate = 103.5 g.; Total Condensate = 2993.5 g.

$$\text{Ratio} = \frac{103.5}{2993.5} = .0346$$

RUN NO. 14

ie	Angle 0° Thermometer Readings Top	Bottom	Air	Draft Gage	R.P.M. Fan	Press. H_2O	Barometer = 758 mm. Thermocouples Top	Bottom
)0	216°	215°	72°	.180	448	10"	3.8	3.8
.5	217	216	72	.180	450	9-3/4	3.8	3.8
30	220	216	71	.180	449	8	3.8	3.8
+5	214	214	71	.180	449	8-1/4	3.8	3.8
)0	220	216	72	.180	449	10	3.9	3.9
.5	220	216	71	.185	450	9-1/4	3.9	3.9
30	220	216	72	.185	450	10	3.9	3.9
+5	221	216	70	.185	450	9	3.9	3.9
)0	220	216	72	.187	450	9	3.85	3.9
.5	223	216	72	.180	450	8-3/4	3.85	3.9

at 12:18

Main Cond. = 2810 g.; Wt. Fin Condensate = 252 g.; Total Condensate = 3062 g.; Ratio = $\frac{252}{3062}$=.0823

Tested with black dye.

RUN NO. 15

Angle 0° Barometer = 758 mm.

.5	214	215	76	.175	454	10-1/4	3.85	3.9-
)	222	216	76	.170	453	10-1/4	3.85	3.9-
5	214	214	76	.170	452	10	3.85	3.9-
)	214	214	76	.170	453	10	3.85	3.9-
5	218	216	76	.170	453	10-1/2	3.85	3.9-
)	219	216	77	.165	453	10-1/2	3.85	3.9-
5	217	216	77	.170	453	10-1/2	3.85	3.9-
)	221	216	78	.175	454	10-3/8	3.85	3.9-
5	217	215	78	.170	453	10-3/4	3.85-	3.9-
)	214	214	78	.175	453	10-1/4	3.85	3.9-

at 3:33

Main Condensate = 2740 g.; Wt. Fin Condensate = 234.5 g.; Total Condensate = 2974.5 g.;

$$\text{Ratio} = \frac{234.5}{2974.5} = .079$$

<u>RUN NO. 16</u>

Angle 0° Barometer = 750 mm.

ime	Thermometer Readings Top	Bottom	Air	Draft Gauge	R.P.M. Fan	Press. H_2O	Thermocouples Top	Bottom
2:12	220°	216°	76°	.175	450	10"	3.85	
2:30	216	214	75	.170	452	10-1/2	3.85	
2:45	216	215	76	.165	452	10-1/2	3.8	
3:00	214	214	76	.175	453	10-1/4	3.8	
3:15	222	216	76	.180	452	10	3.8	
3:30	222	215	75	.190	452	9-3/4	3.8	
3:45	213	214	74	.180	452	10	3.95	
4:00	218	216	76	.180	453	10	3.95	
4:15	220	216	76	.180	453	10	3.95	
4:25	221	216	76	.180	454	10	3.95	

ut at 4:30

t. Main Condensate = 2760 g.; Wt. Fin Condensate = 262 g.; Total Condensate = 3022 g.;

$$\text{Ratio} = \frac{262}{3022} = .0866$$

<u>RUN NO. 17</u>

Angle 0° Barometer 757.3 mm

):53	220	216	70	.160	452	9-1/4	4.0
):00	222	216	71	.185	452	10-1/4	4.05
):15	216	215	70	.180	450	9-1/4	4.05
):30	224	216	72	.190	452	10	4.05
):45	221	216	72	.170	452	9-1/2	4.05
.:00	220	216	71	.190	453	10	4.05
.:15	223	216	74	.175	454	10	4.05
:30	223	216	70	.170	455	9-1/2	4.05
:45	223	214	70	.185	454	8-1/4	4.05
2:00	214	214	72	.170	453	8-3/4	4.05

it at 12:11

. Main Condensate = 2920 g.; Wt. Fin Condensate = 240 g.; Total Condensate = 3160 g.;

$$\text{Ratio} = \frac{240}{3160} = .0760$$

RUN NO. 18

Angle 0°

me	Thermometer Readings Top	Bottom	Air	Draft Gauge	R.P.M. Fan	Press. H_2O	Couple Top	Condensate Fin	Main
06	214°	214°	71+°	.170	452	9-3/4"	4.00	0 cc.	0 g.
11	214	215	71	.165	454	10-1/8	4.00		
16	217.5	215	72.5	.170	453	10-1/4	4.05		
21	219	215.5	72	.165	455	10-1/4	4.05	28.5	315.5
26	219	215	72	.165	455	10-1/2	4.05		
31	224	215	72	.175	455	10-1/2	4.05		
36	218	215	72	.160	454	10-1/2	4.05	56.5	620
41	218	215	71.5	.170	455	10-3/4	4.05		
46	217	215	70	.160	455	10-1/4	4.05		
51	217	215	70	.170	455	10-1/4	4.05	84	932
56	216	215	70	.170	455	10-1/4	4.05		
01	218	215	71	.170	455	10-1/4	4.00		
6	215	215	70	.180	455	10	4.00	113.5	1250
11	217	215	70	.170	455	10	4.00		
16	215	215	69	.175	455	10	4.00		
21	216	215	72	.180	455	10-1/2	4.00	142	1558
26	218	215	73	.165	455	10-1/2	4.00		
31	218	215	71	.185	455	10	4.00		
36	218	215	71	.180	455	10	4.00	170	1868
41	216	215	70	.170	455	10-1/2	4.00		
46	216	215	69	.170	455	10-1/2	4.00		
51	216	215	71	.170	455	10-1/2	4.00	201	2187
56	216	215	72	.185	455	10-1/2	4.00		
01	216	215	69	.175	456	10-1/2	4.00		
06	216	215	69	.160	459	10-1/4	4.00	228.5	2505±
11	215	215	70	.170	451	11	4.00		
16	214	215	69.5	.170	451	10-1/2	4.00		
21	218	215	70	.165	451	10-1/2	4.00		
24								262 g.	2864

$$\text{Final Ratio} = \frac{262}{3126} = .0839$$

RUN NO. 19

Angle 0° Barometer = 761.4 mm.

'ime	Thermometer Readings Top	Bottom	Air	Draft Gauge	R.P.M. Fan	Press. H_2O	Couple Top	Condensate Fin	Main	Ratio
.0:00	214°	215°	70°	.180	450	10-1/2	4.05	0	0	
.0:05	214	215	70	.170	450	10-1/2	4.05			
.0:10	216	215	70	.180	450	10-3/4	4.05			
.0:15	218	215	70	.170	450	10-1/2	4.05	34	316	.0973
.0:20	224	216	72	.165	450	11	4.05			
.0:25	220	216	72	.175	452	11-3/4	4.05			
.0:30	218	215	71	.185	450	11	4.05	69	625	.0995
.0:35	216	215	70	.185	450	11	4.05			
.0:40	217	215	70	.190	452	11	4.05			
.0:45	218	215	70	.190	450	11	4.05	103	942	.0988
.0:50	218	215	71	.180	451	11	4.05			
.0:55	217	215	71	.185	450	11	4.05			
.1:00	215	216	72	.185	452	11-1/4	4.05	136.3	1259	.0978
.1:05	218	215	71.5	.190	453	10-1/4	4.05			
.1:10	216	215	70	.190	452	10	4.05			
.1:15	216	215	69.5	.180	451	10-1/2	4.05	165.3	1630	.0954
.1:20	216	215	69.5	.175	451	10-1/2	4.05			
.1:25	216	215	70	.175	452	11	4.05			
.1:30	214	215	70	.180	451	11-1/4	4.05	195.3	1884	.0932
.1:35	214.5	215	69	.180	451	11-3/4	4.05			
.1:40	215	215	69.5	.180	451	10-1/4	4.05			
.1:45	215	215	70	.190	451	10-1/4	4.05	227.1	2201	.0935
.1:50	216	215	69	.180	451	11	4.05			
.1:55	216	215	70	.175	451	11	4.05			
12:00	218	215	70.5	.170	451	11-1/4	4.05	257.9	2514	.093
12:05	218	215	71	.170	452	11-1/2	4.05			
12:10	220	216	70	.180	451	11-1/2	4.05			
12:15	220	215	70	.175	451	10-1/8	4.05			
12:18								294.4	2881	.0928

RUN NO. 19 (CONT'D)

Time	Thermometer Readings Top	Bottom	Air	Draft Gauge	R.P.M. Fan	Press. H_2O	Couple Top	Condensate Fin	Main	Ratio
Blow out for 15 minutes.										
12:37	220°	215°	70°	.175	451	10-1/8	4.05	0	0	
12:42	221	215	70	.175	452	10-1/2	4.05			
12:47	214	215	69	.175	452	10-1/2	4.05			
12:52	215	215	69	.180	452	9-1/2	4.05	28	314	.082
12:57	214	214.5	69	.175	451	9-1/2	4.05			
12:62	216	215	69.5	.180	450	10	4.05			
1:07	218	215	70	.170	452	10	4.05	30.5	3135	.0888
1:12										

RUN NO. 20

Barometer 761.4 mm

ime	Angle 0° Thermometer Readings			Draft	R.P.M.	Press.	Couple	Condensate		
	Top	Bottom	Air	Gauge	Fan	H_2O	Top	Fin	Main	Ratio
:10	224°	216°	72°	.180	451	12	4.00	0	0	
:15	218	216	71	.180	452	12	4.00			
:20	215	215	71.5	.185	452	11	4.05			
:25	214	215	71	.180	454	11	4.05	29.333	308	.0871
:30	213	215	71	.180	450	11	4.05			
:35	219	216	72	.175	452	11.5	4.05			
:40	216	215	71	.170	451	11	4.05	58.33	619	.0860
:45	214	215	70.5	.180	452	11-1/2	4.05			
:50	219	216	71	.175	451	11-3/4	4.05			
:55	220	216	71.5	.175	451	11-1/8	4.05	88.33	930	.0868
:00	226	216	71.5	.170	451	10-1/4	4.05			
:05	214	215	70.5	.180	450	11	4.05			
:10	215	215	71	.180	450	11-1/4	4.05	116.83	1236.7	.0864
:15	224	216	70.5	.180	450	11-3/4	4.05			
:20	220	215	70.5	.170	451	11-3/4	4.05			
:25	218	215	70	.170	450	11	4.05	146.83	1546	.0867
:30	214	215	70	.175	450	11	4.05			
:35	214	215	70.5	.185	450	11	4.05			
:40	221	216	71	.170	450	11	4.05	176.33	1860	.0867
:45	226	216	70	.175	450	11-1/4	4.00			
:50	216	215	70	.175	450	11	4.00			
:55	214	214	70	.175	450	11	4.00	206.83	2170	.0872
:00	214	214.5	70	.170	450	11	4.00			
:05	217	215.5	70	.170	450	11	4.00			
:10	218	216	70	.185	450	11-1/4	4.00	236.83	2483	.0872
:15	224	216	70	.170	450	11	4.00			
:20	218	216	70	.180	450	10-3/4	4.00			
:25	217	215	69	.180	450	10-3/4	4.00			
:28	218	215	70	.175	450	10-3/4	4.00	273.83	2856	.0874
		Zero Reading		+.01						

RUN NO. 21

Angle 0°

Time	Thermometer Readings Top	Thermometer Readings Bottom	Thermometer Readings Air	Draft Gauge	R.P.M. Fan	Couple Top	Press. H_2O	Condensate Fin	Condensate Main	Ratio
11:38	217°	215°	76°	.175	454	4.00	10-1/2	0	0	
11:43	222	216	74	.165	455	4.00	10-1/2			
11:48	220	216	76	.175	455	4.00	10-1/2			
11:53	218	216	77	.170	454	4.00	10-1/2	22.6	297	.0708
11:58	218	215	77	.175	455	4.00	10-1/2			
11:63	218	215	76	.175	455	4.00	10-1/2			
11:68	217	215	76	.165	455	4.00	10-1/2	45.6	594	.0714
12:12	218	215	76	.170	455	4.00	10-1/2			
12:17	217	215	76	.180	455	4.00	10-1/2			
12:22	218	215	76	.170	455	4.00	10-1/4			
12:27								24	302	.0736
				Nitrogen Added						
12:30	218	215	76	.160	455	4.00	11-1/4	0	0	
12:35	218	215	77	.170	455	4.00	11-1/2			
12:40	221	215	76.5	.170	455	3.96	11-1/2			
12:45	220	216	77	.170	454	3.96	11-1/4	17.5	304.5	.0544
12:50	220	215	78	.165	455	3.96	11-1/2			
12:55	220	215	76	.175	455	3.96	11-1/4			
12:60	220	215	76	.175	455	3.96	11-1/2	35.2	606	.052
1:05	220	215	77	.175	455	3.96	11-1/2			
1:10	218	215	78	.180	455	3.96	11-1/2			
1:15	218	215	76	.175	455	3.96	11-1/4	48.9	910	.051

NEW HOOK UP ON BOILER

RUN No. A

Angle 0°

Barometer = 754 mm.

Time	Thermometer Readings Top	Bottom	Air	Draft Gauge	R.P.M. Fan	Press. H_2O	Condensate Fin	Main	Ratio
2:10	214°	214°	71°	.170	453	9	0	0	
2:15	214	214	71	.165	453	9			
2:20	226	216	71	.165	452	9			
2:25	214	214	71	.160	455	8-3/4	21.2	308	.0645
2:30	214	214	71	.150	453	8-1/2			
2:35	216	215	71.5	.165	455	8-1/2			
2:40	216	215	71	.165	452	8-1/4	42.3	519	.064
		Blow out		2:45 - 3:10					
3:15	222	215	71.5	.160	453	10	0	0	
3:20	214	215	71	.155	453	9-1/2			
3:25	218	215	71.5	.150	453	9			
3:30	218	215	71.5	.165	454	8-1/2	24	304	.0732
3:35	218	215	70.5	.165	454	8			
3:40	220	214	71.	.165	454	8			
3:45	220	215	70	.170	454	8	47.5	607	.0727
3:50	218	215	71	.160	454	7-3/4			
3:55	218	215	71	.150	453	10			
4:00	216	215	71	.160	454	10	72.5	914	.0735
4:05	216	215	70	.170	455	12-1/4			
4:10	220	215	71	.160	453	7-1/2			
4:15	218	215	71	.175	453	7-3/4	98	1217	.0745

RUN NO. C

Angle 0°

Barometer 746.5 mm.

Time	Thermometer Readings Top	Bottom	Air	Draft Gauge	R.P.M. Fan	Press. H_2O	Condensate Fin	Main	Ratio
6:30 (Started Blow-out)									
6:50 (Seals put in)									
7:07	214°	214°	69°	.160	450	10	0	0	
7:12	218	215	72	.160	450	9			
7:17	221	215	70.5	.150	450	11			
7:22	216	213	68	.160	450	11-1/4	25	312	.0742
7:27	214	213	68	.160	450	12			
7:32	215	213	73	.160	450	14			
7:37	220	215	75	.160	450	10	48	620	.071
7:42	223	213	74	.150	450	9-1/4			
7:47	218	215	73	.140	450	8			
7:52	216	214	75	.160	450	10	71	916.5	.0719
7:57	215	214	69	.160	450	8-1/2			
8:02	217	214	74	.160	450	7-3/4			
8:07	218	214	75	.160	450	12	94.5	1216.5	.072
Out at 8:12									
Blow out until 8:30									
8:45	222	214	75	.150	451	10	0	0	
8:50	215	214	75	.160	451	11			
8:55	214	213	75	.160	452	8			
9:00	218	215	75	.160	450	12	25	305	.0758
9:05	217	215	75	.160	452	10-1/2			
9:10	216	215	76	.160	452	8			
9:15	227	215	75	.160	450	8-1/2	48	599	.0743
9:20	220	214	75	.160	450	8-1/2			
9:25	213	213	75	.160	452	8			
9:30	219	215	74	.150	450	8-3/4	71	900	.073
9:35	230	215	74	.160	452	8			
9:40	222	215	75	.160	452	8-1/4			
9:45	214	213	74	.160	450	7	94	1196	.0728
9:50	214	214	75	.160	453	12			
9:55	228	216	75	.160	455	13			
10:00	218	215	74	.160	452	8	120.5	1503	.074

RUN NO. C (CONT'D)

Time	Thermometer Readings Top	Bottom	Air	Draft Gauge	R.P.M. Fan	Press. H_2O	Condensate Fin	Main	Ratio
10:05	213°	213°	74°	.150	453	8			
10:10	214	213	74	.160	453	8			
10:15	220	215	74	.150	457	8	144.5	1810	.074
10:20	228	215	75	.165	455	9-1/4			
10:25	226	215	74	.150	455	9-1/4			
10:30	222	215	74	.165	455	9-3/4	168	2108	.0739
Cut at 10:35		Blow off until - 11:10							
11:20	219	215	74	.140	420	12	0	0	
11:25	213	213	75	.160	453	8			
11:30	220	215	74	.160	450	9			
11:35	222	215	74	.160	450	8-1/2	25.5	297	.079
11:40	216	215	73	.160	450	8-3/4			
11:45	216	215	74	.160	450	8-3/4			
11:50	225	215	73	.150	452	8-1/2	52	591	.0809
11:55	215	213	75	.160	450	8-3/4			
12:00	214	214	73	.160	452	8-3/4			
12:05	214	214	74	.165	451	8-3/4	77	890	.0796
12:10	214	214	72	.160	451	8-1/4			
12:15	216	214	72	.160	452	8			
12:20	218	214	74	.160	448	9-3/4	103.8	1195	.0800
12:25	215	215	74	.160	450	9-1/4			
12:30	214	214	74	.170	451	9-1/4			
12:35	214.5	214	74	.160	448	8-1/2	128.3	1492	.0792
Cut at 12:35									

RUN NO. C (CONT'D)

Time	Thermomter Readings Top	Bottom	Air	Draft Gauge	R.P.M. Fan	Press. H_2O	Condensate Fin	Main	Ratio
	Changed adjustment of valves so that rate of bleeding is higher. Did not blow off.								
1:00 A.M.	221°	216°	74	.160	450	9-1/2	0	0	
1:05	219	215	71	.160	450	9			
1:10	216	214	72	.160	450	8-3/4			
1:15	218	214	72	.160	450	8-3/4	26.0	300	.0798
1:20	220	215	72	.160	450	8-3/4			
1:25	219	215	72	.160	450	8-3/4			
1:30	219	215	70	.160	448	8-1/2	51.5	598	.0743
1:35	218	215	72	.160	448	8-1/4			
1:40	220	215	70	.160	448	8-1/2			
1:45	221	216	73	.160	448	9	78	897	.0800
1:50	218	215	74	.155	448	9			
1:55	217	215	74	.160	448	9-1/4			
2:00	217	215	74	.160	447	9-1/4	105	1189	.0811
Cut at 2:00		Blow off until 2:35 A.M.							
3:05	214	214	72	.155	449	9-3/4	0	0	
3:10	214	214	72	.160	450	10-1/2			
3:15	214	214	73	.155	451	10-1/2			
3:20	215	215	72	.155	450	10-1/4			
3:25	214	214	72	.150	455	8-3/4			
3:30	215	215	71	.150	449	9-1/2			
3:35	218	215	72	.155	447	9	51.9	602	.0793
3:40	216	214	73	.160	447	9-1/2			
3:45	216	214	74	.160	448	9-1/2			
3:50	215	214	72	.160	448	9-1/4			
3:55	214	214	72	.160	447	9-1/4			
4:00	220	215	72	.150	447	9-1/2			
4:05	215	214	72	.160	448	10-1/4	104.9	1200.1	.0803
Cut at 4:05									

Drop air temp. without blowing off or otherwise altering adjustments.

RUN NO. C (CONT'D)

Barometer = 751.3 (4:30 A.M.)

Time	Thermometer Readings Top	Bottom	Air	Draft Gauge	R.P.M. Fan	Press. H_2O	Condensate Fin	Main	Ratio
A.M.									
4:30	222°	216°	66	.160	450	9-3/4			
4:35	222	216	66	.160	450	9-3/4			
4:40	222	216	66	.160	450	10-1/4			
4:45	214	214	64	.160	450	9-1/4			
4:50	214	214	65	.170	450	9-1/4			
4:55	217	215	64	.170	450	9-1/2			
5:00	217	215	64	.165	450	9-3/4	54.5	630.9	.0796
5:05	217	214	66	.160	450	9-1/4			
5:10	216	215	64	.160	450	9-1/4			
5:15	217	215	66	.155	438	10-1/4			
5:20	218	215	66	.160	450	10-1/4			
5:25	219	215	65	.160	448	10-1/4			
5:30	219	215	65	.160	448	9-3/4	108.4	1257.1	.0794
Cut at 5:30		Blow out until 6:00 A.M.							
6:20	218	215	66	.160	450	10			
6:25	221	216	66	.160	450	9-1/2			
6:30	220	216	65	.170	450	9-1/2			
6:35	218	215	66	.165	450	9	28.4	311.3	.0836
6:40	220	216	66	.170	449	9-1/2			
6:45	220	216	64	.165	445	9			
6:50	218	215	66	.160	450	9			
6:55	218	215	66	.160	450	8-1/2			
7:00	216	215	65	.170	450	8-1/2			
7:05	216	214	66	.170	451	9	85.6	942.1	.0834
7:10	220	215	65	.165	450	9			
Cut at 7:05									

Now attempt to revert to conditions of 72-74°F. runs.

RUN C (CONT'D.)

Barometer = 753.1 at 8:10 A.M.

Time	Thermometer Readings			Draft	R.P.M.	Press.	Condensate		
	Top	Bottom	Air	Gauge	Fan	H_2O	Fin	Main	Ratio
A.M.									
7:45	223°	216°	74°	.160	454	9-3/4			
7:50	220	216	74	.155	453	9-1/4			
7:55	220	215	74	.165	453	9-1/4			
8:00	220	215	75	.160	451	10-1/4	27.0	2932	.0844
8:05	222	216	74	.160	451	9-3/4			
8:10	218	215	74	.150	449	9-1/2			
8:15	218	216	72	.160	449	9-3/4	53.4	588.2	.0833
8:20	218	215	73	.160	450	9-3/4			
8:25	216	214	73	.155	448	10			
8:30	220	215	73	.150	448	10	80.5	881.9	.0837
8:35	220	215	73	.160	448	10-3/4			
8:40	222	216	74	.160	449	9-1/2			
8:45	214	214	72	.160	449	9-1/2	107.1	1177.1	.0834
Cut out at 8:45		Blew out.							
9:45	214	214	74	.160	447	9-3/4	0	0	
9:50	218	215	73	.160	449	9-1/2			
9:55	221	216	73	.150	447	9-1/4			
10:00	220	215	72	.155	448	9	25.5	299.5	.0797
10:05	221	215	73	.150	447	9			
10:10	220	215	72	.160	447	9-1/4			
10:15	219	215	74	.150	449	9-1/2	52.3	591.2	.0814
10:20	220	215	74	.160	448	8-3/4			
10:25	220	215	74	.155	447	8-3/4			
10:30	220	215	74	.160	447	8-3/4	78.3	882.2	.0815
10:35	221	215	75	.155	445	9			
10:40	222	215	75	.155	446	9			
10:45	223	215	75	.15	447	9	104.7	1174.2	.0821

THERMOMETER CALIBRATIONS

	No.19513 Exit Steam	No. 29497 (air)	No.34727 (Entering Steam)
B.P.	212°F.	211.5°F.	211.5°F
Barometer	766.4		
Room Temp.	82°F	82°F	
F.P.	32.5°F	32.5°F.	

DRAFT GAUGE CALIBRATION

Differential Manometer Reading " Alcohol Sp. Gr. .82	Corrected Manometer Reading " Water	Draft Gauge
1.000	.820	.823
.900	.738	.738
.800	.656	.654
.700	.574	.570
.600	.492	.490
.500	.410	.410
.400	.328	.328
.300	.246	.245
.200	.164	.161
.100	.082	.082
.000	.000	.000

HORIZONTAL TRAVERSE

Barometer - 766.0

Distance from East Wall	Draft Gauge Reading	Temp.	R.P.M.
22.5"	.040	80°	450
19.5"	.135	80	450
16.5"	.170	80	450
13.5"	.170	80	450
10.5"	.170	80	450
7.5"	.160	80	450
4.5"	.135	80	450
1.5"	.025	80	450
1.5"	.020	80	450
4.5"	.130	80	450
7.5"	.150	80	450
10.5"	.160	80	450
13.5"	.160	80	450
16.5"	.180	80	450
19.5"	.135	80	450
22.5"	.050	80	450
1.5"	.020	80	450

Optimum Position for Tube - 7.5" from west wall.

VERTICAL TRAVERSE

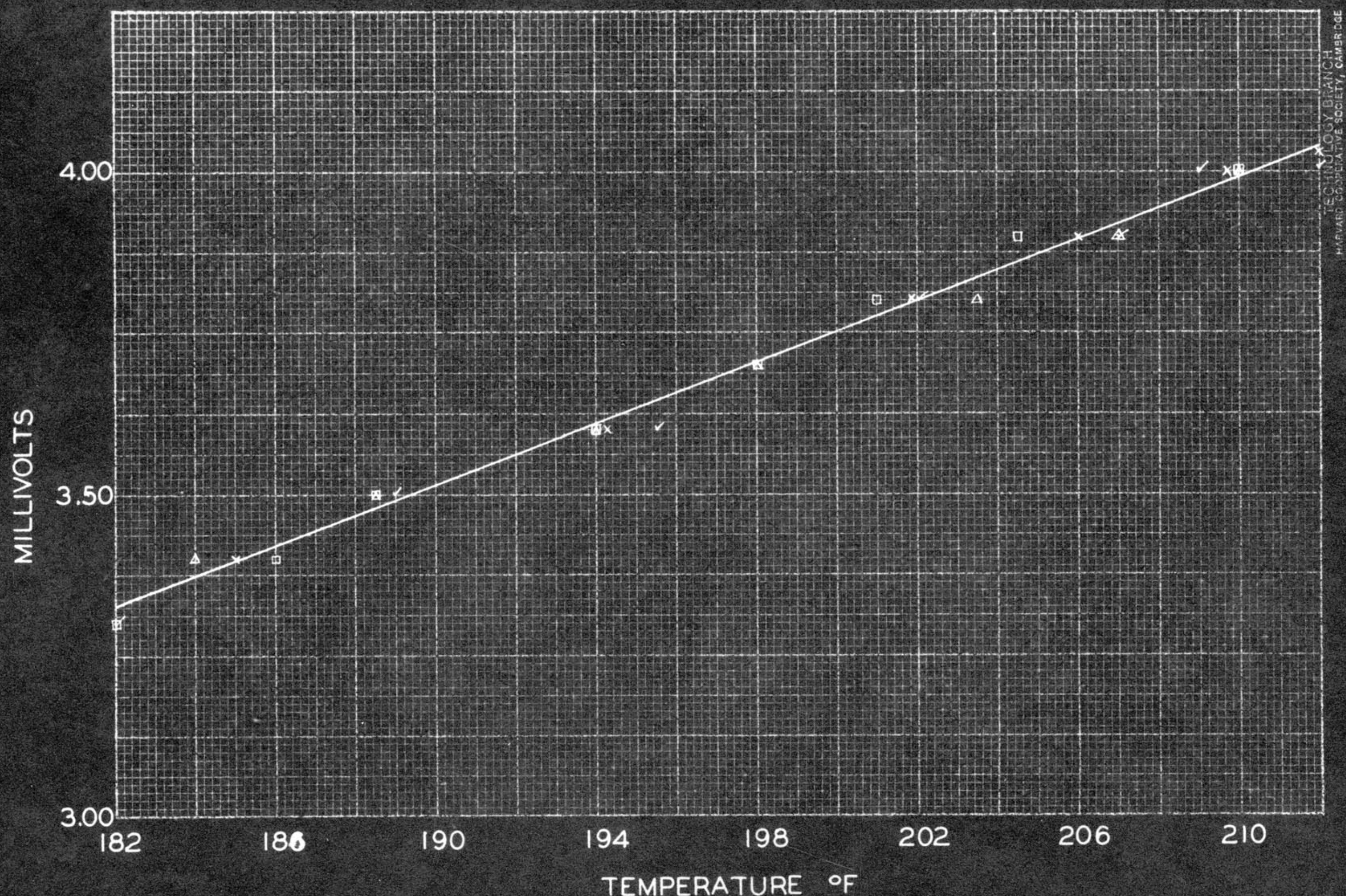
Distance from Bottom	Draft Gauge	Draft Gauge	Temp.	R.P.M.
1.5"	.090	.095	81°	450
4.5"	.100	.110	81	450
7.5"	.130	.140	81	450
10.5"	.140	.140	81	450
13.5"	.150	.150	81	450
16.5"	.150	.155	81	450
19.5"	.150	.150	81	450
22.5"	.130	.125	81	450
25.5"	.150	.145	81	450
28.5"	.110	.110	81	450

TRAVERSE AFTER TOP SHEET OF TIN ADDED

Air Temp. - 76°/R.P.M. Fan 450
Barometer - 750 mm.

Vertical Traverse

Distance from bottom	Draft Gauge	Draft Gauge
1.5"	.12	.110
4.5"	.115	.115
7.5"	.155	.155
10.5"	.165	.160
13.5"	.170	.165
16.5"	.165	.170
19.5"	.165	.170
22.5"	.145	.130
25.5"	.140	.150
28.5"	.12	.125



CALIBRATION OF COPPER-IDEAL THERMOCOUPLE

SAMPLE CALCULATIONS

Run No. 1

Average Temp. 78°

$212-78 = 134° = (\Delta t)_{ave.}$

$A = 3 \times \pi(\frac{2.125}{12}) = 1.67$ sq. ft.

$\theta = 2.0167$ hrs.

Total heat of superheated steam = 1171

Heat of Liquid = 180

$$Q = \frac{1609}{454}(1171 - 180)$$

$$= \frac{1609}{454}(991)$$

$$= 3510$$

$$Q/\theta = HA(\Delta t)_{ave.}$$

$$\frac{3510}{2.0167} = H(1.67)(134)$$

$$H = \frac{3510}{2.0167 \times 1.67 \times 134}$$

$$= 7.8 \text{ B.t.u./hr./sq.ft./°F.}$$

BIBLIOGRAPHY

BIBLIOGRAPHY

1. J.T.Morris, Engineering, 96, 1913, page 178.

2. Boussinesq, J. (a) "Theorie analytique de la chaleur", Gauthier-Villars, Paris 1903.

   (b) J. Math. pures et appl. I. 285, 1905.

3. Alexander Russell, Philosophical Magazine, Vol. 29, July - Dec. 1910.

4. L. V. King, Philosophical Transactions (A) 214, 1914. Page 373.

5. T. E. Stanton, Technical Report of Advisory Committee for Aeronautics, 1912-1913 (45).

6. Rubach, Forschungsarbeiten Heft 185, Page 3.

7. Hughes, Phil. Mag. 31 (1916) Page 118.

8. Chappell and McAdams, Transactions A.S.M.E., 1926, Page 1218.

9. Dickermann, M.I.T. Undergraduate Thesis 1929.